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Late-Glacial to early Holocene Climate Changes from a Central Appalachians Pollen and Macrofossil Record

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ABSTRACT

A Late-glacial to early Holocene record of pollen, plant macrofossils and charcoal, based on two cores, is presented for Browns Pond in the central Appalachians of Virginia. An AMS radiocarbon chronology defines the timing of moist and cold excursions, superimposed upon the overall warming trend from 14,200 to 7,500 ^{14}C yr B.P. This site shows cold, moist conditions from approximately 14,200 to 12,700 ^{14}C yr B.P., with warming at 12,730, 11,280 and 10,050 ^{14}C yr B.P. A decrease in deciduous broad-leaved tree taxa and *Pinus strobus* (haploxylon) pollen, simultaneous with a re-expansion of *Abies* denotes a brief, cold reversal from 12,260 to 12,200 ^{14}C yr B.P. A second cold reversal, inferred from increases in montane conifers, is centered at 7500 ^{14}C yr B.P. The cold reversals at Browns Pond may be synchronous with climate change in Greenland, and northwestern Europe. Warming at 11,280 ^{14}C yr B.P. shows the complexity of regional climate responses during the Younger Dryas chronozone.

INTRODUCTION

Are the late-glacial climate oscillations that have been extensively documented in pollen records from western and northern Europe evident in eastern North America? Recent pollen records from Atlantic Canada (Mayle *et al.*, 1993), the northeastern U.S. (Peteet *et al.*, 1990; Peteet *et al.*, 1993; Maenza-Gmelch, 1997a; Maenza-Gmelch, 1997b), and the U.S. midwest (Shane, 1987; Shane and Anderson, 1993), are interpreted as showing cold reversals that are synchronous with the European Younger Dryas chronozone (*sensu* Mangerud *et al.*, 1974). In addition, temperature estimates based on chironomid assemblages show cooling events of just 250 years duration that are recorded in Maritime Canada, called the Killarney Oscillation, (Levesque *et al.*, 1993) and Maine (Cwynar and Levesque, 1995). Therefore, evidence is accumulating that cold reversals interrupted the deglacial warming trend in eastern North America.

South of these glaciated regions, late-glacial cool or moist periods have been recognized in pollen records from Kentucky to Florida (Watts, 1980; Watts and Hansen, 1988; Wilkins *et al.*, 1991; Watts *et al.*, 1992). Reviews of southeastern pollen records and climatic interpretations have been written by Delcourt and Delcourt (1984; 1985) Overpeck *et al.* (1989), Watts (1983), and Watts and Hansen (1994). However, the duration of these cool and moist periods, and their possible connection to climate changes in the northern North Atlantic Basin, have not been firmly established.

Identifying climate reversals on the order of 100 to 1000 years in existing unglaciated eastern U.S. records is difficult: slow sedimentation rates combined with few radiocarbon dates make it difficult to resolve events of this time scale. We examined cores from a central Appalachians pond where accumulation rates averaged 70 cm per 1000 ^{14}C yr from 14,000 to 10,000 ^{14}C yr B.P. The pollen and

abundant macrofossils, combined with AMS radiocarbon dating, have produced a detailed record of late-glacial to early Holocene vegetation change at this site.

METHODS

Browns Pond is a 60 by 20 meter basin, with no inlets, in the central Appalachians of Virginia, U.S.A. at 38°09'17"N, 79°36'59"W, and 620 m elevation. Water depth is approximately 20 cm. The underlying bedrock is upper-Silurian age limestone, sandstone and shale (Bick, 1962). Despite the karst topography, at this site the colluvium is sandstone-rich and soils are acidic (T. Rawinski, personal communication, 1991). The closest weather station, in Hot Springs, Virginia (38°00'N, 79°50'W, 682 m) has an annual average temperature of 10.8°C and 1060 mm of precipitation (NOAA, 1983). The pond is covered with *Dulichium arundinaceum* (three-way sedge). The site is in the Ridge and Valley section of the Oak-Chestnut Forest region described by Braun (1950) and the trees immediately surrounding the site are typical of this region: *Quercus alba* and *Q. rubra* predominate. A more detailed description of the site and vegetation can be found in Kneller and Peteet (1993).

Previously six cores were retrieved in a partial transect across the pond. The identification of pollen and plant macrofossils was concentrated on the central and longest core (named BR89) which dated to 17,130 ^{14}C yr B.P. at 400-cm depth, and reached a total depth of 697 cm depth (lower meters are inorganic clay) (Kneller and Peteet, 1993). All core depths are relative to the sediment-water interface. The primary results from the previous paper were: 1) a boreal-type forest consisting of *Picea, Abies,* and *Pinus* grew at the site at 17,300 ^{14}C yr B.P. and slight increases in more thermophilous and mesophytic taxa occurred after 17,000 ^{14}C yr B.P.; 2) a marked increase in *Alnus* at 14,100 ^{14}C yr B.P. signaled an increase in moisture. Core BR89 had slow sedimentation rates and poor preservation between approximately 13,000 and 8000 ^{14}C yr B.P. In order to determine the vegetation

changes occurring during this time interval, we analyzed more samples from transect core BR91 since it had better preservation during the late-glacial to Holocene transition (BR91 is referred to as BRW1 in Kneller and Peteet (1993) and due to coring difficulties was only 228 cm in length). We also retrieved new cores from Browns Pond and concentrated our analyses on the core with the most complete recovery, here called BR92. All cores were retrieved with a 5 cm diameter modified Livingstone piston corer (Wright *et al.*, 1984). Since the sediments were very consolidated, drives are less than 1 m in length.

We present new results from cores BR91 (228 cm deep) and BR92 (512 cm deep) which are approximately 22 and 18 m east of BR89, respectively. Most pollen and macrofossil identifications were conducted on BR92 since it was the longest core (Figures 1 and 2). At the top of the third drive, a gap exists from 174.5 to 186 cm depth (below the sediment surface). Hence core BR91 was examined in detail from 170 to 225 cm depth in order to confirm the stratigraphy (Figures 3 and 4).

Pollen processing followed Faegri and Iverson (1975) with the modifications of Heusser and Stock (1984). A known quantity of *Lycopodium* spores was added in order to calculate pollen accumulation rates (PAR) or pollen influx (Figure 5), (Stockmarr, 1971). Plant macrofossils were identified in sediments that were prepared according to Watts and Winter (1966) and Peteet (1986). A half-core was cleaned on the outer surface and then cut into segments at intervals of 1 to 2 cm. The screen sizes used to separate macrofosssils from sediment were 120 and 500 microns. A volumetric estimate of charcoal content was made on the sediment fraction > 500 microns.

Pollen classification follows McAndrews *et al.* (1988) and Faegri *et al.* (1989). *Alnus rugosa* and *A. crispa* types were distinguished according to Watts (1979). Morphological criteria do exist to distinguish the pollen of three species of *Picea* presently found in eastern North America (Birks and Peglar, 1980; Hansen and

Engstrom, 1985). However, the relevance of these criteria to *Picea* pollen from the southern Appalachians needs further evaluation (B. Hansen, personal communication, 1992) and hence *Picea* pollen identification remains at the genus level. The CONISS program for stratigraphically constrained cluster analysis (square root transformation) was applied to the upland pollen taxa in order to help define the local pollen assemblage zones (Grimm, 1987). Plant macrofossils were identified with the aid of Martin and Barkley (1961), Montgomery (1977), and Lévesque *et al.* (1988) and by comparison to the reference collection at Lamont-Doherty Earth Observatory. Nomenclature follows Fernald (1970) except where noted otherwise.

AMS radiocarbon dated samples were identified macrofossils from trees or emergent aquatics; sediment was used when no macrofossils were available (Table 1). Previously, dates on macrofossils and bulk sediment from the same depths showed virtually no offset (Kneller and Peteet, 1993). AMS radiocarbon analyses were conducted by the Center for Accelerator Mass Spectrometry, Lawrence Livermore National Laboratory, California and the National Science Foundation Arizona AMS Facility. CALIB version 3.0.3c (Stuiver and Reimer, 1993) was used to derive the calibrated sidereal years (cal yr B.P., Table 1). The age model for Browns Pond is a straight-line interpolation between radiocarbon dates (see the plot of Deposition Time in Figure 5).

RESULTS and INTERPRETATION

Pollen and Plant Macrofossils

The radiocarbon dates for cores BR92 and BR91 are generally in chronological order (Table 1). The three nearly synchonous 10,000 ^{14}C yr B.P. dates, separated by 23 cm, in core BR91 may indicate either rapid sedimentation rates, or be an expression of the radiocarbon age plateau identified at approximately 10,000 ^{14}C yr B.P. (Andreé *et al.*, 1986; Ammann and Lotter, 1989; Kromer and Becker, 1993). Without an independent age model, a plateau cannot be confirmed.

The pollen and plant macrofossil assemblages are interpreted in light of existing phytosociological studies that show tree distribution along elevational gradients in the Appalachians. Nearly pure fir (*Abies fraseri* or *A. balsamea*) stands characterize the highest elevation forests in much of the southern and northern Appalachians. *Abies* shows the greatest tolerance to cold; *Picea* usually is more abundant at elevations below *Abies* (Oosting and Billings, 1951; McIntosh and Hurley, 1964; Siccama, 1974; Reiners and Lang, 1979; Cogbill and White, 1991). In the Appalachian montane spruce-fir forest, unlike the North American boreal forest, *Picea rubens* is the dominant spruce species below approximately 47°40'N latitude, not *Picea glauca* or *Picea mariana* (Little, 1971; Cogbill and White, 1991). The *Picea*- and *Abies*-dominated stands grade into lower-elevation stands containing deciduous trees. *Betula* is the one deciduous tree that is consistently found in many of the high-elevations forests, although the species may vary (e.g. *B. lutea, B. papyrifera, B. papyrifera* var. *cordifolia* and *B. lenta*). *Fagus grandifolia, Acer saccharum* and *Acer rubrum, Fraxinus americana, Tilia heterophylla* and *Tilia americana, Quercus rubra,* and the conifer *Tsuga canadensis* are frequent components of mid-elevation forests.

Alternatively, the taxa could be interpreted in light of their continental distribution, especially with reference to their high-latitude distribution. The elevation-analogy is used here because the plant associations interpreted from the fossil record, between 12,700and 7500 ^{14}C yr B.P., are very similar to associations found in the modern phytogeographic studies from the Appalachians. There are floristic differences between the high-elevation montane spruce-fir forest, and the high latitude or boreal forest. Many high-latitude taxa have their southernmost appearance in the central Appalachians (Gleason and Cronquist, 1991). We have not yet identified taxa, in the Browns Pond sediments, that are unequivocally boreal rather than montane. A major climatic difference is that the Appalachians at high-

elevations receive more precipitation than the high latitudes (Oosting and Billings, 1951).

Zone BR1: *Picea-Abies* zone (≥ 14,180 ^{14}C yr B.P.; BR92, 445 to ≥ 485 cm). This zone is similar to the *Pinus-Picea-Abies* zone dating from 17,345 to 14,090 ^{14}C yr B.P. in core BR89 (Kneller and Peteet, 1993). One dissimiliarity is that in core BR92, the percentages of *Picea* pollen (from 42 to 46%) are greater than *Pinus* pollen (from 29 to 38%) whereas in BR89 *Pinus* exceeds *Picea* pollen percentages. In both cores, the arboreal macrofossils are mostly *Picea* needles.

Zone BR2: *Alnus-Picea-Abies* zone (14,180 to 12,730 ^{14}C yr B.P.; 17,000 to 15,000 cal yr B.P.; BR92, 445 to 346 cm). This zone is defined by significant amounts of *Alnus rugosa*-type pollen, which reaches a maximum of 26%. It correlates with the *Alnus-Pinus-Picea-Abies* zone in core BR89 dating from 14,090 to 12,810 ^{14}C yr B.P. (in which *Alnus rugosa*-type pollen ranged from 30 to 59% (Kneller and Peteet, 1993)). *Picea, Pinus* and *Abies* reach maximum percentages of 32, 26, and 5.6 respectively. *Quercus* (3.0%) and *Betula* (2.6%) have the highest percentages of the deciduous-tree taxa. The herbaceous assemblage comprises a range of plants including Gramineae, Cyperaceae, Tubuliflorae, other Compositae, and *Nuphar*. Total upland pollen influx ranges from 1400 to 6000 grains cm^{-2} yr^{-1}.

Macrofossil preservation is excellent. *Picea* needles and seeds are the most abundant macrofossils, followed by *Abies* needles, and *Alnus* seeds and cone bracts. A few *Larix* seeds, fragments of 2 per fascicle *Pinus* needles, and *Pinus* seed cone scales were found. The *Pinus* specie(s) could not be identified since the needle fragments are small and the cone scales lack bracts, which can be help identify species. A single *Betula* seed, *populifolia* type (Cunningham, 1957), was identified at 365 cm. Seeds of the shrubs *Sambucus canadensis* and *Rubus* sp., and herbs including *Hypericum virginicum* var. *Fraseri, Viola* cf. *lanceolata* and *Menyanthes trifoliata* are present. *Isoetes melanopoda* megaspores and microspores are

abundant. This is an amphibious species found in springtime saturated and summer dry conditions (Fernald, 1970; Boom, 1982). Aquatic seeds are common and include *Nuphar*, two species of *Potamogeton*, and *Najas flexilis*. Charcoal concentrations ranges from 0 to 1.2 mm^3 per ml of sediment.

A montane spruce-fir forest, established by 14,180 ^{14}C yr B.P. is indicated by the significant percentages of pollen from *Picea* and *Abies*, and their abundant seeds and/or needles. Alder likely grew in moist soil near the pond. The array of arboreal and shrub macrofossils suggests a densely covered, mesophytic landscape surrounding a pond. The water depth was deeper than today, based on the presence of *Nuphar* and *Potamogeton*. Water-levels were lower in summer than in spring, based on the presence of *I. melanopoda*.

The transition between pollen zones BR2 and BR3a is placed at 346 cm depth, between pollen samples at 343.5 and 348.5 cm depth, even though the CONISS analysis shows a distinct division between pollen samples at 348.5 and 361.5 cm depth. Our zone division is based upon increases in percentage, concentration and influx of *Quercus*, *Ostrya/Carpinus*, and *Fagus*, that are evident in the samples starting at 343.5 cm depth (Figures 1, 5 and (Kneller, 1996)).

Zone BR3a: *Picea-Abies-Ostrya/Carpinus-Quercus* zone (12,730 to 12,260 ^{14}C yr B.P.; 15,000 to 14,320 cal yr B.P.; BR92, 346 to 266 cm). This zone is delineated by increases in some broad-leaved deciduous-tree pollen taxa. *Quercus*, *Ostrya/Carpinus*, *Fagus* and *Juglans* reach maximum pollen percentages of 13.6, 3.8, 1.9 and 0.6 respectively, levels which likely show the taxon's presence (Davis and Webb, 1975; Delcourt *et al.*, 1984). *Picea*, *Pinus* and *Abies* remain significant components of the pollen assemblage. *Nuphar* pollen percentages increase while *I. melanopoda* microspores are absent. Other aquatics include *Typha/Sparganium*, *Menyanthes* and *Sagittaria*.

Pollen influx rises, and ranges from 5900 to 22,000 grains cm^{-2} yr^{-1}. The influx increase is apparent in many taxa. The influx increase might be partly caused by increased slope inwash, or sediment focusing, since it coincides with higher sedimentation rates. However, while total pollen concentration is approximately constant across the zone BR2-BR3a boundary, the concentration of the different tree taxa varies. Pollen concentrations of *Ostrya/Carpinus* increase by roughly ten-fold at zone BR3a's lower boundary, *Quercus* increases by about four-fold, *Picea* and *Abies* by roughly two-fold, and *Pinus* shows little change in concentration (Kneller, 1996). Maximum influx values for *Ostrya/Carpinus* are in this zone. Thus a real increase in numbers of deciduous trees, especially *Ostrya/Carpinus* and *Quercus*, likely occurred at 12,730 ^{14}C yr B.P.

Arboreal macrofossils preserved include *Pinus strobus* needles, 2 per fascicle *Pinus* needles, and seeds and/or needles of *Picea, Abies* and *Larix. Alnus* seeds decrease within this zone. A single *Acer spicatum* seed occurs at 343 cm. Seeds of several herbaceous plants become abundant: *Verbena* cf. *hastata, Carex stipata, Scirpus polyphyllus* type, *S. atrovirens* type and *Sagittaria* cf. *rigida.* Aquatics include Nymphaeaceaeseeds, along with scattered occurrences of *Potamogeton spirillus*-type and *P. foliosus*-type seeds. Charcoal concentration is from 0 to 0.75 mm^3 per ml of sediment.

A step towards warmer temperatures at 12,730 ^{14}C yr B.P. is inferred from the increases in *Quercus, Ostrya/Carpinus, Fagus* and *Juglans* pollen, and decreases in the seeds of *Menyanthes trifoliata* (a circumboreal aquatic). The array of conifer and deciduous taxa suggests a region like the transition from the subalpine conifer zone to the northern hardwoods-yellow birch-mesophytic forest zone found in the Balsam Mountains of Virginia (Rheinhardt and Ware, 1984): cooler and moister than present. The marsh and aquatic taxa are typical of temperate eastern North

American ponds. *Nuphar* seeds and pollen indicate water levels deeper than present.

Two small but distinct peaks in *Tsuga* pollen (in percentage and influx) are evident from 287 to 282 cm (two pollen samples of 9 to 12%) and at 267.5 cm (one sample of 3.7%). The first two occurrences of *Tsuga* needles are at 282 and 267 cm depth, additional evidence that the *Tsuga* population increased at this site. The *Tsuga* peaks are also concurrent with increases in *Pinus* haploxylon-type pollen and *Dryopteris*-type spores, and decreases in *Picea* and *Abies*. *Tsuga* and *Pinus strobus* are species found at elevations lower than *Abies* and *Picea* in the Appalachians. These changes may be caused by warming temperatures, although replication in other cores from this site and neighboring sites is needed prior to interpreting a regional event.

Zone BR3b: *Abies-Picea*-diploxylon *Pinus* zone (12,260 to 12,200 ^{14}C yr B.P.; 14,320 to 14,240 cal yr B.P.; BR92, 266 to 245 cm). Percentages and influx of *Abies* pollen increases. Many of the deciduous-tree taxa decrease (*Ulmus, Ostrya/Carpinus, Quercus, Juglans cinerea* and *Fagus grandifolia,* but neither *Fraxinus* nor *Betula*). The pollen percentages of these deciduous-tree taxa are similar to their zone BR2 values. *Tsuga* pollen and macrofossils are absent. *Pinus* diploxylon-type pollen increases, *Picea* pollen influx increases. The pollen percentages of *Sanguisorba canadensis* increase while *Typha/Sparganium* decrease. Total pollen influx ranges from 4200 to 22,000 grains cm^{-2} yr^{-1}.

Seeds from some shallow water, temperate species which were abundant in zone BR3a, are now absent. *Carex stipata, Scirpus polyphyllus* type and *S. atrovirens* type are now absent along with the herb *Verbena* cf. *hastata*. Definitive identification of these species is needed in order to interpret the environmental change. *Menyanthes trifoliata* seeds are present. Charcoal concentration ranges from 0 to 0.8 mm^3 per ml of sediment.

A reversal toward colder temperatures explains the rise in percentage and influx of *Abies* pollen, decreases in *Pinus* haploxylon-type pollen and *Pinus strobus* needles, and decreases in percentage and influx of the deciduous-tree taxa pollen. Other taxa showing increases in pollen influx—*Picea*, *Pinus* diploxylon-type pollen, and *Sanguisorba canadensis*—are cold tolerant plants. *M. trifoliata*'s presence shows the pond had shallow water areas.

Zone BR3c: *Picea-Abies-Ostrya/Carpinus-Quercus* zone (12,200 to 11,280 ^{14}C yr B.P.; 14,240 to 13,260 cal yr B.P.; BR92, 245 to 195 cm). The pollen and macrofossil assemblage is very similar to zone BR3a except *Abies* macrofossils are absent, and *Tsuga* needles more abundant in BR3c. Total pollen influx ranges from 2200 to 6500 grains cm^{-2} yr^{-1}. Pollen from *Lycopodium annotinum* and *Menyanthes trifoliata*, circumboreal species, and *Sanguisorba canadensis* are last seen here.

Temperatures warm and return to climate conditions like those from 12,730 to 12,260 ^{14}C yr B.P. (zone BR3a). Two more small *Tsuga-Pinus* haploxylon-type pollen, and *Tsuga* macrofossil peaks (at 238 cm and 216 cm) could be related to warming. This interpretation must be substantiated at additional sites.

At this point, the assemblages from both cores BR91 and BR92 are used to define the pollen zones. Pollen influx curves, and the CONISS results on core BR91 where our sampling resolution was higher, were all evaluated when making the divisions between zones BR3c, BR4, and BR5. Where the two cores overlap chronologically, the pollen and macrofossil assemblages are similar in composition although differences exist in the exact percentage of any taxon counted, and the exact stratigraphic placement of fluctuations of one taxon relative to another. The differences could be due to factors affecting pollen accumulation within the basin (Davis *et al.*, 1984). Also, a core's proximity to the shoreline (itself a fluctuating feature over time) might register different ratios of the shore and shallow-water

plants, especially if the pollen was not well-mixed throughout the basin prior to deposition.

Zone BR4: *Tsuga-Betula-Pinus strobus*-zone (11,280 to 10,050 ^{14}C yr B.P.; 13,260 to approximately 10,940 cal yr B.P.; BR92, 195 to 173 cm; BR91, > 225 to 203 cm). Dated fossils are near the beginning of the zone in core BR92 (BR91 did not penetrate all of zone BR4). Dating the top of zone BR4 is more subjective. In core BR92, the 173 cm depth is about 10,040 ^{14}C yr B.P. with our age model. However, in core BR91, the top of zone BR4 at 203 cm depth is among three dates ranging from 9945 to 10,190 ^{14}C yr B.P. (Table 1). We approximate the end of zone BR4 at 10,050 ^{14}C yr B.P.

The dominance of *Tsuga* pollen (from 23 to 62% in BR92, 21 to 56% in BR91), distinct increases in *Betula* (reaching a maximum of 9.5% in BR92 and 20% in BR91) and *Pinus* haploxylon-type pollen, and a unique maximum in *Sphagnum* spores, characterize this zone. Decreases in percentages of *Picea*, *Quercus*, Cyperaceae and Tubuliflorae pollen accompany the *Tsuga* rise. Cyperaceae, *Abies* and *Ostrya/Carpinus* pollen become rare. Total pollen influx is 2300 to 7200 grains cm^{-2} yr^{-1}. The influx of *Tsuga*, *Betula* and *Pinus* haploxylon-type pollen increases, *Quercus* does not. Pollen from the aquatics, *Typha/Sparganium*, *Nuphar*, and *Sagittaria*, decreases from the zone BR3c values.

Tsuga and *Picea* macrofossils are numerous, often exceeding 10 needle fragments each per 1 ml of sediment in core BR91. Two species of hemlock are recognized in eastern North America, *Tsuga canadensis* is the most dispersed and *T. caroliniana* is confined to the Appalachians from Virginia to Georgia (Godman and Lancaster, 1990; Gleason and Cronquist, 1991). The three *Tsuga* seed-bearing (megasporangiate) cones from this zone, in length and scale shape, are more similar to *Tsuga canadensis*. One entire *Picea* pollen-bearing (microsporangiate) cone and several pollen-bearing cone fragments occur in this zone (we could not identify the

species). A few *Pinus strobus* needles and one *Larix* seed were found. *Betula* seeds and bracts are most abundant in this zone. Many of the *Betula* achenes are missing the wings and stigmas and thus species identification is difficult. Those *Betula* seeds which are finely pubescent just below the stigma were classified as *Betula papyrifera*-type (Cunningham, 1957). However the pubescent characteristic may not be unique to *Betula papyrifera* (Radford *et al.*, 1968; Fernald, 1970; Gleason and Cronquist, 1991)

Seeds of *Sambucus canadensis*, a swamp shrub, and a single seed of the shade-tolerant shrub, *Taxus canadensis*, were identified. Decreases in *Nuphar* pollen, and the absence of Nymphaeaceae and *Nuphar* seeds, indicate water levels have dropped. Charcoal concentration in core BR91 varies between 0 and 3.6 mm^3 per ml of sediment.

A temperature increase is inferred from the *Tsuga* increase and *Abies* decrease in both pollen and macrofossils. Throughout the Appalachians today, *Tsuga* is found at lower elevations than *Abies*. *Picea*'s presense is consistent with warming temperatures if the species is *P. rubens*; this species is presently found with *Tsuga* and *P. strobus* in the central Appalachians (Eyre, 1980 p. 26-27). *Tsuga* is a long-lived (from 300 to 800 years), very shade-tolerant tree that prefers a cool, humid climate (Rogers, 1978; Godman and Lancaster, 1990). *P. strobus* is tolerant of drier conditions, although the two trees may grow on more mesic sites or hummocks in wooded swamps (Jorgensen, 1978 p. 276; Powell, 1980).

Zone BR5: *Nyssa-Tsuga-Quercus* zone (10,050 to 8410 ^{14}C yr B.P.; approximately 10,940 to approximately 9400 cal yr B.P.; BR92, 173 to 134 cm; BR91, 203 to <143 cm). Within this zone *Quercus* replaces *Tsuga* as the dominant pollen taxon. A series of changes occurs in tree-taxa pollen in core BR92: *Nyssa* rises from 2.3% at 173 cm to a high of 10.5% at 145 cm, at 152 cm *Picea* drops below 1% and *Abies* below 0.5%, *Diospyros* appears at 148 cm. Of all the taxa represented in the pollen diagrams, *Diospyros* unambiguously has the most southerly distribution,

occurring below 41°N latitude and south to peninsular Florida (Halls, 1990). The same pollen sequence occurs in core BR91 although the percentages differ. Total influx ranges from 5000 to 1800 grains cm^{-2} yr^{-1} at the end of this zone, *Quercus* influx increases gradually from 430 to 2100 grains cm^{-2} yr^{-1}.

Macrofossils are nearly absent and the sediment is very inorganic. In BR92, a single *Cornus canadensis* seed was identified at 172 cm. In BR91, Compositae, *Glyceria striata*-type and *Sparganium* cf. *americanum* seeds were found. The presense of *Typha/Sparganium* and *Polygonum lapathifolium* type pollen, the absense of *Nuphar* pollen at the top of the zone, along with significant amounts of *Nyssa* pollen, all indicate the pond has been largely replaced by wet ground or marshland. Charcoal concentrations are highest at the base of this zone. The concentations in BR91 range from < 1 to 8 mm^3 per ml of sediment, in core BR92 the maximum concentration is 2.9 mm^3 per ml of sediment. Thus, a fire and opening of the forest canopy are inferred. Increases in *Pteridium* and Polypodiaceae spores support this interpretation.

Warming temperatures explain the increasing influx of *Quercus*, *Nyssa* and *Diospyros*, and decreasing influx of *Tsuga* and *Betula* pollen. In zone BR5, the influx of *Quercus* pollen increases gradually yet *Nyssa* and *Diospyros* exhibit rapid increases. A similar pattern occurs in concentration (Kneller, 1996). Possibly the local populations of *Nyssa* and *Diospyros* trees expanded more rapidly than *Quercus*. *Picea* pollen percentages fluctuate greatly: a single peak of 25% occurs at 181.5 cm, in core BR92 there is much less fluctuation. The cause of the *Picea* fluctuations is unclear. The continued presence of significant *Tsuga* pollen supports the argument that climate is still as moist as modern conditions in the southern low-elevation Appalachians.

Zone BR6: *Quercus-Carya* zone (8410 to <4870 ^{14}C yr B.P.; approximtely 9400 to 5600 cal yr B.P.; BR92, 134 to <65 cm). *Carya* pollen, which has been at roughly 1%

during the preceding zones, now rises to 4.4% at 134 cm and reaches a high of 11% at 72 cm. *Quercus* pollen ranges from 40 to 71% while *Tsuga* pollen decreases from 31 to <5% by 97 cm. Total pollen influx ranges from 2700 to 7600 grains cm^{-2} yr^{-1}.

Salix buds and one seed each of *Crataegus* and *Rubus* were identified. Aquatic and low-ground plant seeds come from several *Carex* species, *Polygonum* cf. *punctatum*, and at least three *Potamogeton* species. Characeae oogonia are present. Charcoal concentration ranges from < 1 to 4.5 mm^3 per ml of sediment.

Fluctuations in water quality and depth can explain the variations in aquatic and wet ground taxa. The pollen of swamp-ground taxa, *Ilex* and *Cephalanthus occidentalis*, occur throughout the zone. Their percentages decrease slightly as *Nuphar* pollen returns above 100 cm depth, which indicates an increase in water levels.

At 7500 ^{14}C yr B.P., a brief return to a colder, still moist climate is inferred from the resurgance in *Tsuga* (16%), *Picea* (4.5%) and *Abies* (1.0%). The increases (from a single sample at 103 cm depth) are noticable in the concentration diagram and just perceptible in influx. The fact that three cold-tolerant taxa exhibit synchronous increases in pollen percentage, concentration and influx point to a short reversal to colder temperatures. However, since this conclusion depends on a single sample, other sites must be found in order to substantiate the local and regional significance of the cold reversal.

Water-level Fluctuations

Previously we inferred water-level fluctuations in Browns Pond based upon changes in aquatic plants and the lithostratigraphy; we proposed that the lowest lake levels occurred from 10,000 to 8000 ^{14}C yr B.P. (Kneller and Peteet, 1993). An inorganic sand-clay layer with slower sediment accumulation rates and a decrease in aquatic pollen percentages was identified from 176 to 130 cm depth in the previously-studied central core, BR89. This inorganic layer occurred in five

additional cores taken in a transect across the pond. We hypothesized that a lowering in water-level depth, driven by climate, had created this relatively inorganic layer dating to the early Holocene.

The new analysis of cores BR92 and BR91 substantiates the earlier conclusion that the pond's water levels were lowest during the early Holocene. Based on the lithostratigraphy and organic content measurements, the inorganic clay layer is between 210 and 164 cm depth in core BR91, and 186 and 140 cm depth in BR92 (Kneller, 1996). In these cores, the period of low organic content and slowest accumulation rates occurs between approximately 10,000 and 8500 ^{14}C yr B.P. During this time aquatics, perhaps best exemplified by *Nuphar*, are at their lowest percentages. However, the trees represented in the pollen assemblage require moist conditions. Today, *Tsuga* grows in regions where annual precipitation ranges from <740 to 1270 mm. (Godman and Lancaster, 1990). *Nyssa* and *Diospyros*, which co-occur in the pollen assemblage with *Tsuga* from 10,000 to 7500 ^{14}C yr B.P., presently grow where annual average precipitation is at least 1000 mm and often exceeds 1200 mm (Halls, 1990; Johnson, 1990; Kossuth and Scheer, 1990; McGee, 1990; Outcalt, 1990). Apparently, annual average precipitation was approximately equal to present-day values, even as the pond's water levels were lower than present.

The apparent lower water-level without a decrease in precipitation might be explained by increased evaporation, increased drought frequency, infilling of the pond, a changing depositional center over time—or some combination of climate and non-climatic factors. Determining the cause of the water-level fluctuations is difficult since the basinal depression is, and likely always was, irregular in shape (i.e. not perfectly conical). Thus very likely, sediment and pollen have accumulated at varying rates across the pond (Davis *et al.*, 1984), and the location of the depositional center and shoreline have shifted over time. For example, the beginning of the *Alnus-Picea-Pinus* zone occurs at 445 cm depth (14,100 ^{14}C yr B.P.) in BR92, yet at 337

cm depth (14,090 ^{14}C yr B.P.) in core BR89. Thus at 14,000 ^{14}C yr B.P., core BR92 was in the deeper section of the pond. Total pollen influx also differs between cores BR92 and BR89. The differences could be caused by depositional or post-depositional (e.g. erosional or oxidational) processes (Donner *et al.*, 1978; Davis *et al.*, 1984). Evidence for changes in water quality also comes from *Sphagnum* and Characeae, which occur in acidic and basic conditions respectively. In cores BR89 and BR92, Characeae oogonia were identified from the bottom of the cores up to approximately 12,730 ^{14}C yr B.P., when *Sphagnum* leaves or spores occur. At approximately 8000 ^{14}C yr B.P., *Sphagnum* disappears and Characeae oogonia re-appear. A complete gridded transect of the pond is necessary to determine conclusively which inferred changes in water-level represent a basin-wide drop in water-level.

DISCUSSION

Questions remain about this record of late-glacial/early Holocene vegetation. First, if the *Picea* species present at anytime at Browns Pond is *P. glauca* or *P. mariana* and not *P. rubens*, would this substantially change the climatological interpretations? In Pennsylvania, Watts (1979) tentatively identified pollen from all three spruce species in late-glacial sediments. However, for the reasons stated by H. Delcourt (1979), we were unable to definitively identify the species of our spruce pollen and macrofossils. Each species has different climatological and ecological affinities. Definitive identification of the species would aid in the environmental reconstruction. Second, how accurate is the qualitative climate interpretation based on analogy with the montane forests of the Appalachian Mountains? Quantitative climate reconstructions could be made by statistically comparing each fossil pollen spectrum with modern pollen surface samples obtained from throughout North America. However, several issues must be resolved before proceeding with the

statistical comparisons. The fossil pollen spectra recorded in each of the three radiocarbon dated cores (BR89, BR91 and BR92) agree qualitatively, but not quantitatively, with each other. For example, in the late-glacial sediments, the ratio of *Picea* to *Pinus*, or *Picea* to *Alnus*, varies between cores BR89 and BR92 (see description of the pollen zones). Distance of each core to the shoreline might partially explain the different percentages recorded. Additional modern pollen surface samples from the Appalachians are needed in order to capture the full range of plant associations recognized in the modern phytogeographic studies.

The sequence of temperature fluctuations interpreted at this central Appalachians site shows striking similiarities and dissimilarities to the sequence of events in other pollen stratigraphies and polar ice cores from the North Atlantic region. We interpret temperatures cooler than present from 14,180 to 10,000 ^{14}C yr B.P.

The step towards warming at 12,730 ^{14}C yr B.P. seen at Browns Pond probably represents a change over much of the U.S. southeast since sites in Tennessee (Delcourt, 1979), South Carolina (Watts, 1980), and Florida (Watts and Hansen, 1994) show increases in temperate pollen taxa (*Quercus, Carya, Fagus, Fraxinus* and *Ostrya/Carpinus*) dating between 12,800 and 12,500 ^{14}C yr B.P. This warming is contemporary with warmings seen in pollen records from the U.S. northeast (Peteet *et al.*, 1993; Peteet *et al.*, 1994; Maenza-Gmelch, 1997b; Maenza-Gmelch, 1997a). Thus the warming may have been synchronous from roughly 29° to 41°N latitude along the eastern margin of North America. It should be substantiated by evaluating additional sites especially since a radiocarbon plateau of constant ^{14}C age occurs at this time (Ammann and Lotter, 1989; Kitagawa and van der Plicht, 1998). The North American warming may also coincide with the onset of warming inferred from pollen records in northern and western Europe (Björck and Möller, 1987; Ammann and Lotter, 1989; Watts *et al.*, 1996) and the abrupt rise in delta ^{18}O (Johnsen *et al.*,

1992; Björck *et al.*, 1998) and snow accumulation-rates (Alley *et al.*, 1993) in the Greenland ice cores.

The Browns Pond record shows cold reversals at 12,200 and 7500 ^{14}C yr B.P., superimposed upon the overall warming trend. The first reversal (centered at about 14,280 cal yr B.P.) may correlate to the European Older Dryas chronozone which Mangerud (1974) constrained between 12,000 and 11,800 ^{14}C yr B.P. Subsequent palynology in Sweden revised the dating of the Older Dryas chronozone to between 12,150 and 12,000 ^{14}C yr B.P. (Björck, 1984; Björck and Möller, 1987). The second cold reversal dates to 7500 ^{14}C yr B.P. (between 8200 and 8300 cal yr B.P.). It coincides with CH_4 minimums in the GRIP and GISP2 ice cores, and the most noticeable Holocene decrease in delta $^{18}O_{ice}$ (Chappellaz *et al.*, 1993; Sowers and Bender, 1995; Alley *et al.*, 1997). It also coincides with an ice-rafting event in the North Atlantic Ocean linked to changes in surface circulation (Bond *et al.*, 1997), and a 200-year cooling inferred from oxygen isotopes in lake Ammersee, Germany (von Grafenstein *et al.*, 1998). The cold reversals at this site in the central Appalachians may be concurrent with cold events in the northern high latitudes and shifts in trade-wind strength in the tropical Atlantic Ocean (Hughen *et al.*, 1996; Björck *et al.*, 1998). However, the inherent errors in radiocarbon dating, and the samples' statistical errors, leave room for uncertainty.

The shift to relatively warmer climate at 11,350 ^{14}C yr B.P. is significant for it may show the southern limit of cooling on the eastern margin of North America, contemporaneous with the Younger Dryas chronozone. The late-glacial rise in hemlock and decrease in fir pollen, which indicates warming at Browns Pond, is also apparent at two sites just to the north (Buckles Bog, 39°34'N 79°16'W (Maxwell and Davis, 1972) and Big Run Bog, 39°07'N, 70°35'W (Larabee, 1986)) although the timing is less well constrained. Other records in the U.S. southeast do not clearly show a cooling at this time. Only at Jackson Pond, Kentucky, have *Picea*

fluctuations from 11,300 and 10,040 ^{14}C yr B.P. been hypothesized to represent a Younger Dryas climate oscillation (Wilkins *et al.*, 1991).

Increasing warmth and moisture at 11,300 ^{14}C yr B.P. in the central Appalachians can be consistent with a cold reversal in the northern North Atlantic region. If a steep temperature gradient exists between cold sub-polar waters and warmer subtropical waters, then storm-track associated moisture will be concentrated along the maximum thermal gradient. GCM climate simulations support this hypothesis—when northern North Atlantic sea surface temperatures were cooled, a net increase in precipitation minus evaporation occured at the southern edge of strong temperature contrast (Rind *et al.*, 1986; Keffer *et al.*, 1988). The global extent of a cold reversal contemporaneous with the Younger Dryas chronozone, from 11,000 to 10,000 ^{14}C yr B.P., and its causes is still in debate (Peteet, 1995).

Ideally other unglaciated east coast sites, with high-resolution chronologies, are needed both to confirm the timing, and to define the regionality of the brief cold reversals seen here in the central Appalachians. The diversity of vegetation, and close proximity of ecotonal boundaries in this region, permits a rapid response of the vegetation to changing climate. The great similarity in the timing of climate events seen in this terrestrial mid-latitude vegetation record, when compared to polar ice core and northern european pollen records, suggests a strong coupling of the atmosphere-ocean climate system.

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TABLE 1

Radiocarbon and calibrated years for dated samples, cores BR91 and BR92

Lab Sample number	Sample depth (cm)	Material Dated	Dry Weight (mg)	^{14}C years (yr B.P.)	Calibrated years*
NSF Arizona AA 17723	**BR92** 100	1 *Carex lupulina* seed 2 *C. crinata* seeds 2 conifer cone scales 4 *Salix* buds	2.65	7500 ± 60	8310,8220,8218 (8339-8171)
Lawrence Livermore 17319	**BR92** 152.0	sediment	4100	8890 ± 60	9906 (9969-9870)
17322	**BR92** 194.8-196.4	4 *Picea* needle bases 2 *Picea* needle tips 4 needle fragments 1 *Alnus* cone scale (partial)	2.37	11280 ± 60	13190 (13280-13110)
17323	**BR92** 244.0-245.6	3 *Picea* needle bases 2 *Picea* needle tips 6 *Picea* sterigmata 4 needle fragments 5 *Carix lurida* seeds	2.75	12200 ± 70	14240 (14406-14091)
17324	**BR92** 259.8-261.4	2 *Picea* needles 2 *Picea* needle bases 3 *Rubus* seeds nut fragment	3.27	12230 ± 70	14278 (14446-14127)

17325	**BR92**	1 *Picea* needle	3.78	12730 ± 60	15001
	344.7-346.0	partial conifer needle			(15173-14812)
		17 *Picea* sterigmata			
		conifer cone bract			
		1/3 *Rubus* seed			
		3 2/3 *Carex lurida* seed			
		1/2 Nymphaceae seed			
		Menyanthes fragment			
	BR92				17004
17326	445.0	sediment	2300	14180 ± 60	(17115-16895)
	BR91				11464. . .11225
AA 17724	199.0-200.0	8 *Sparganium* seeds	4.45	10050 ± 75	(11828-11050)
AA 17725	**BR91**	23 *Picea* needle pieces	2.2	10190 ± 75	11939
	207.0-208.0	2 *Picea* sterigmata			(12134-11659)
		2 *Tsuga* stem fragments			
		10 *Tsuga* needle bases			
AA 17726	**BR91**	18 *Picea* needle pieces	2.1	9945 ± 105	11073, 11061,
	222.0-223.0	38 *Tsuga* needle bases			11034
		2 *Tsuga* stem pieces			(11536-10996)
		2 *Sambucus* seeds			

* The first number (or set of numbers) is the calibrated age. The numbers in the parantheses are the range of the calibrated age, at the one sigma level. Sample AA 17724 has nine calibrated ages, only the youngest and oldest are printed here.

FIGURE LEGENDS

FIG. 1. Pollen percentage diagram from Core BR92. A minimum of 300 upland tree, shrub or herbaceous pollen grains were counted; aquatics, unknowns and indeterminables (Cushing, 1967) and pteridophytes were also tallied. The total of tree, shrub and upland herb pollen is used to calculated their percentages. Aquatics are calculated as a percentage of all pollen, pteridophytes as a percentage of all pollen and spores. The stippled silhouette represents a 5x exaggeration of the percentages. Radiocarbon dates are listed in uncorrected years. Core lithology is described according to the Troels-Smith classification as amended by Aaby and Berglund (1986). Organic content was measured on samples of approximately 2 ml according to the procedure in Dean (1974). The drive boundaries, indicated by the dashed lines, are at 82, 174.5, (the top of this drive, from 174.5 to 186 cm, was lost due to coring difficulties in the field) 263, 353.5, 443, 477 and 521 cm depth (measured from the sediment-water interface).

FIG. 2. Plant macrofossils counted in core BR92, per interval, and normalized to to a 1 ml sediment volume. Charcoal concentration is given in mm^3 per ml of sediment. The actual volume of each sediment sample is graphed on the far right in ml.

FIG. 3. Pollen percentage diagram from Core BR91, approximately 4 m west of BR92. Pollen percentages are calculated as they were for core BR92. The drive boundaries are at 87, 187 and 228 cm depth.

FIG. 4. Plant macrofossil and charcoal diagram from Core BR91. Fossils counts are normalized to to a 1 ml sediment volume. Charcoal concentration is given in mm^3 per ml of sediment.

FIG. 5. Pollen accumulation rate (PAR), or pollen influx, diagram for selected taxa in core BR92. The age axis is based on the assumption of a constant

accumulation rate between radiocarbon dates. Note that the horizontal axis changes in scale for each pollen taxa. Units of PAR are in number of pollen grains per cm^2 per year.

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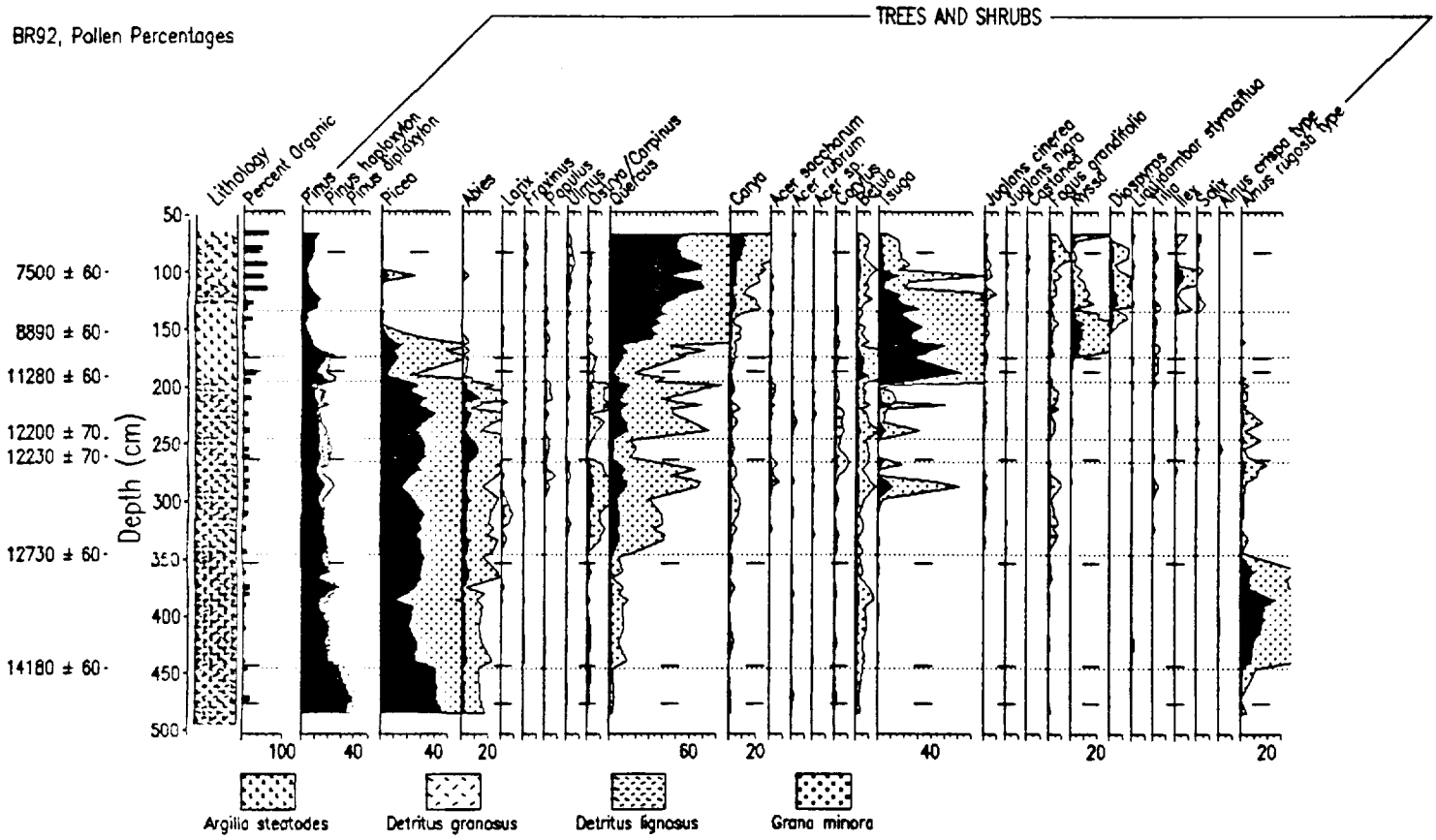
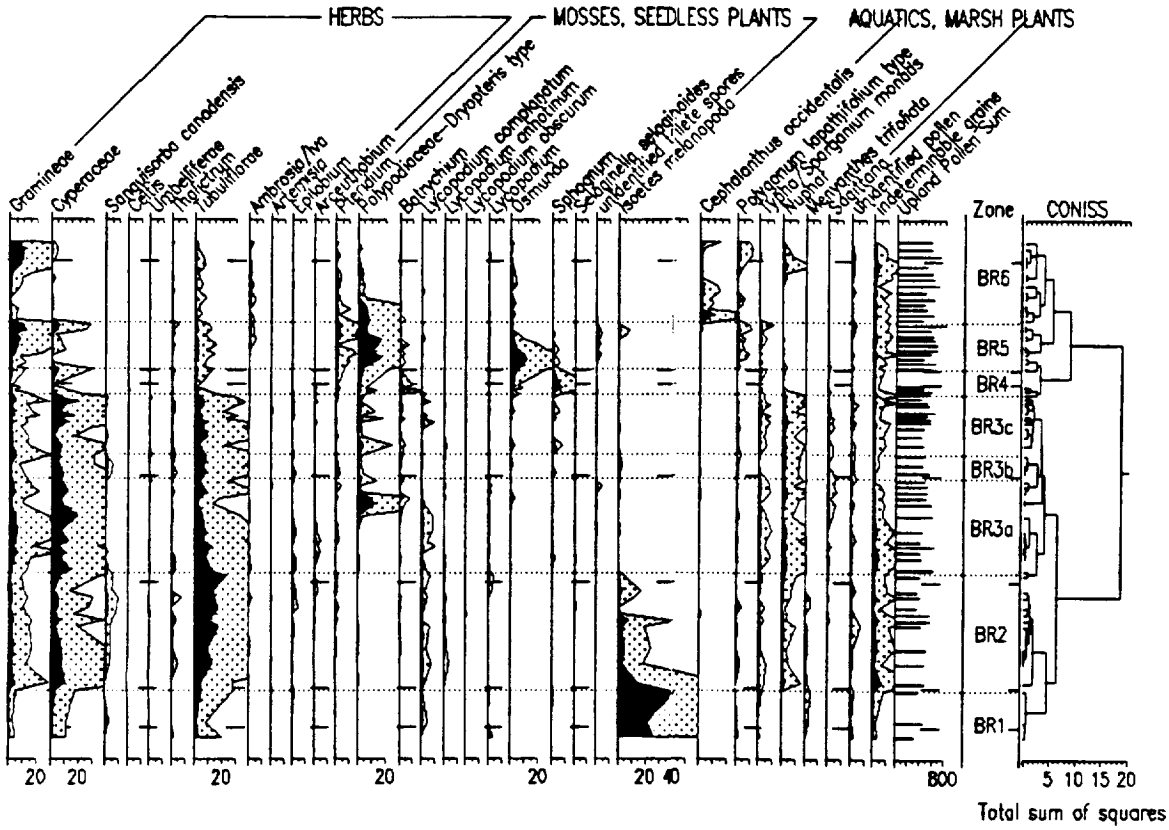
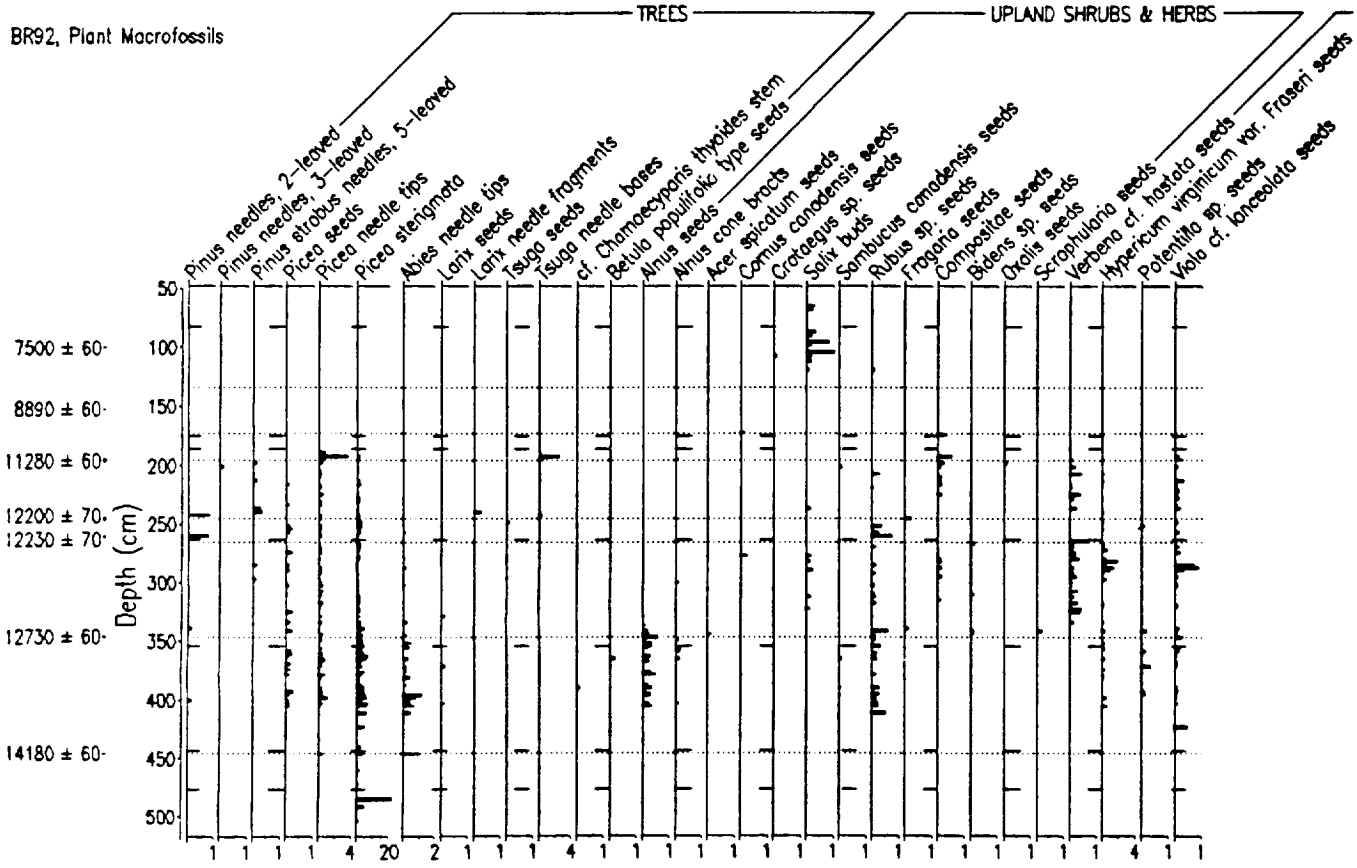
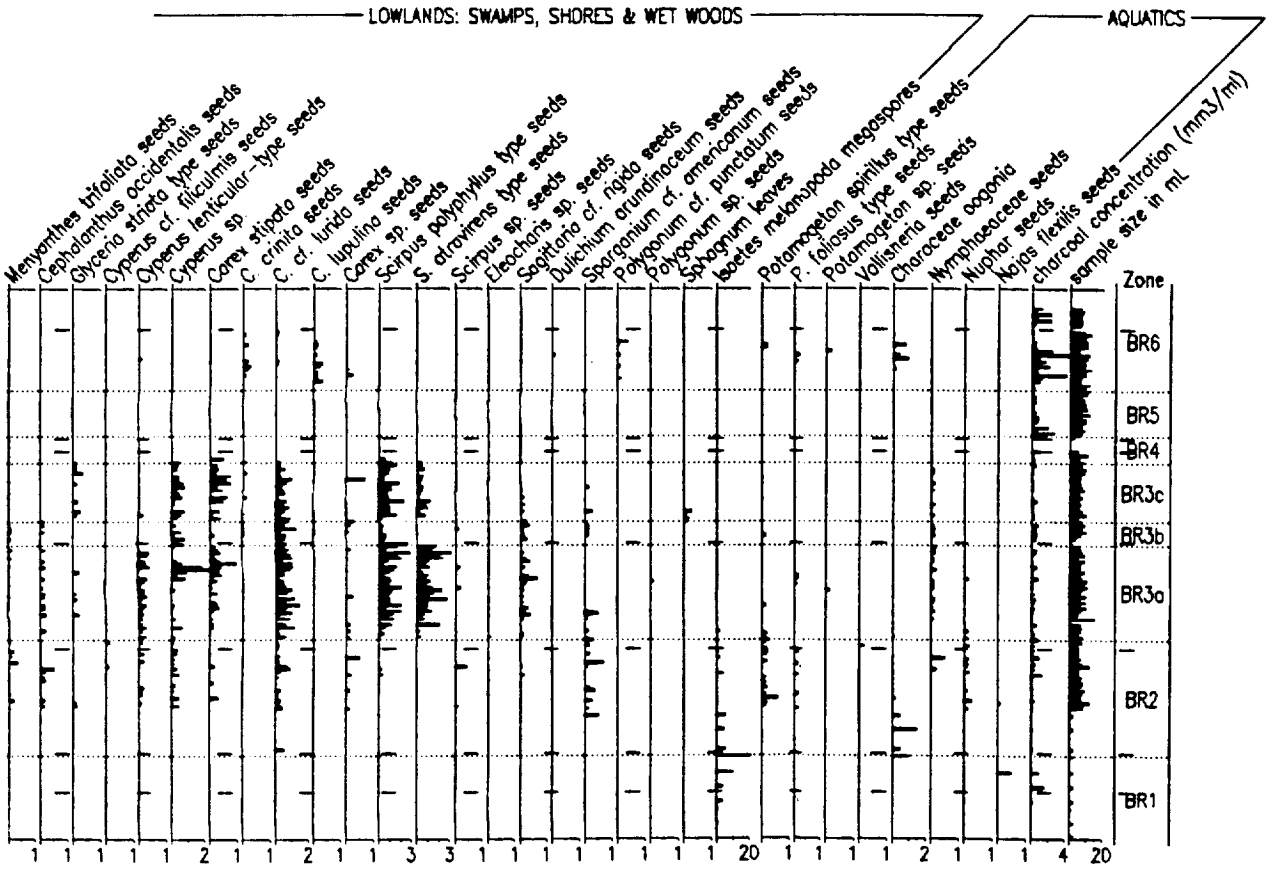
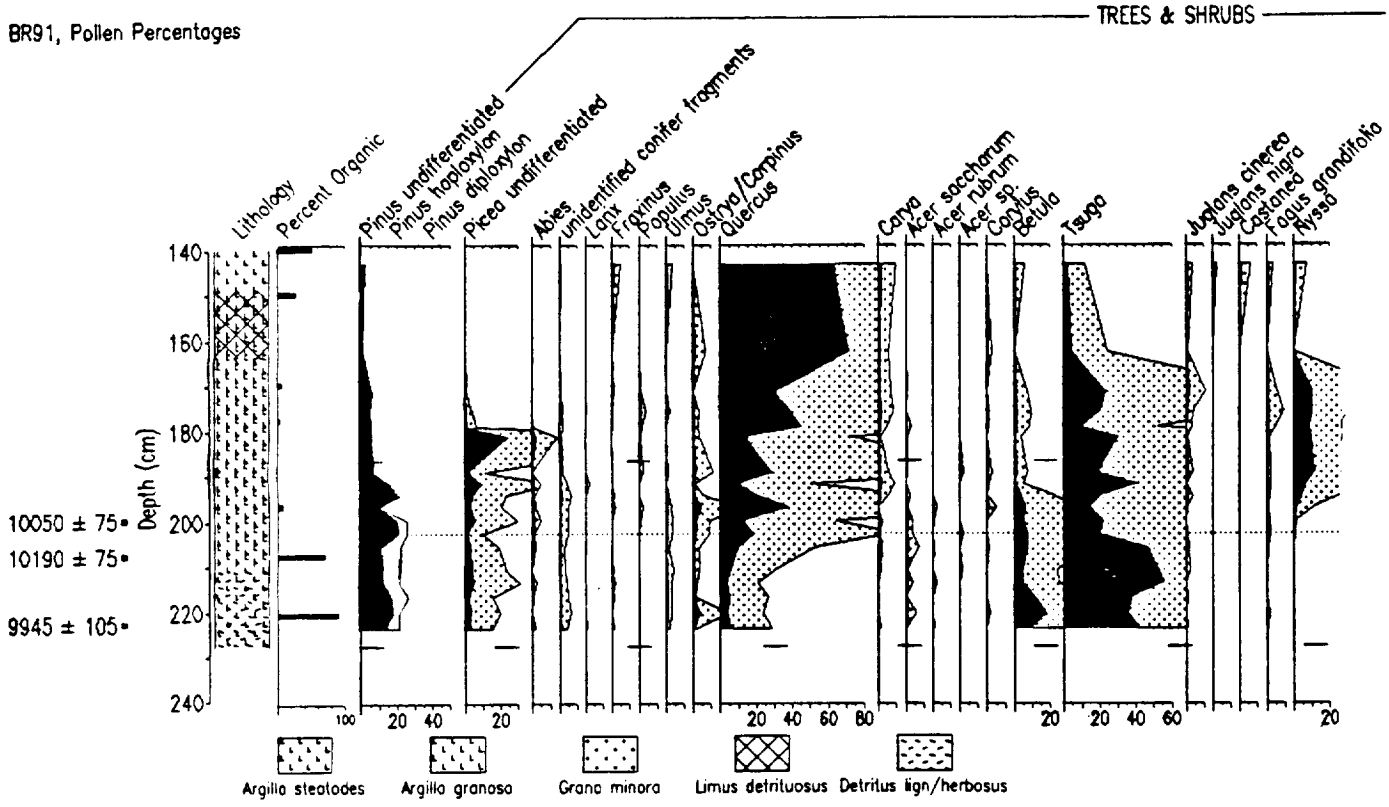

BR92, Pollen Percentages
TREES AND SHRUBS
Lithology
Percent Organic
Pinus
Pinus haploxylon
Pinus diploxylon
Picea
Abies
Larix
Fraxinus
Populus
Ulmus
Ostrya/Carpinus
Quercus
Carya
Acer saccharum
Acer rubrum
Acer sp.
Castanea
Betula
Tsuga
Juglans cinerea
Juglans nigra
Castanea
Fagus grandifolia
Nyssa
Diospyros
Liquidambar styraciflua
Tilia
Ilex
Salix
Alnus crispa type
Alnus rugosa type
Depth (cm)
7500 ± 60
8890 ± 60
11280 ± 60
12200 ± 70
12230 ± 70
12730 ± 60
14180 ± 60
Argilla steatodes
Detritus granosus
Detritus lignosus
Grana minora

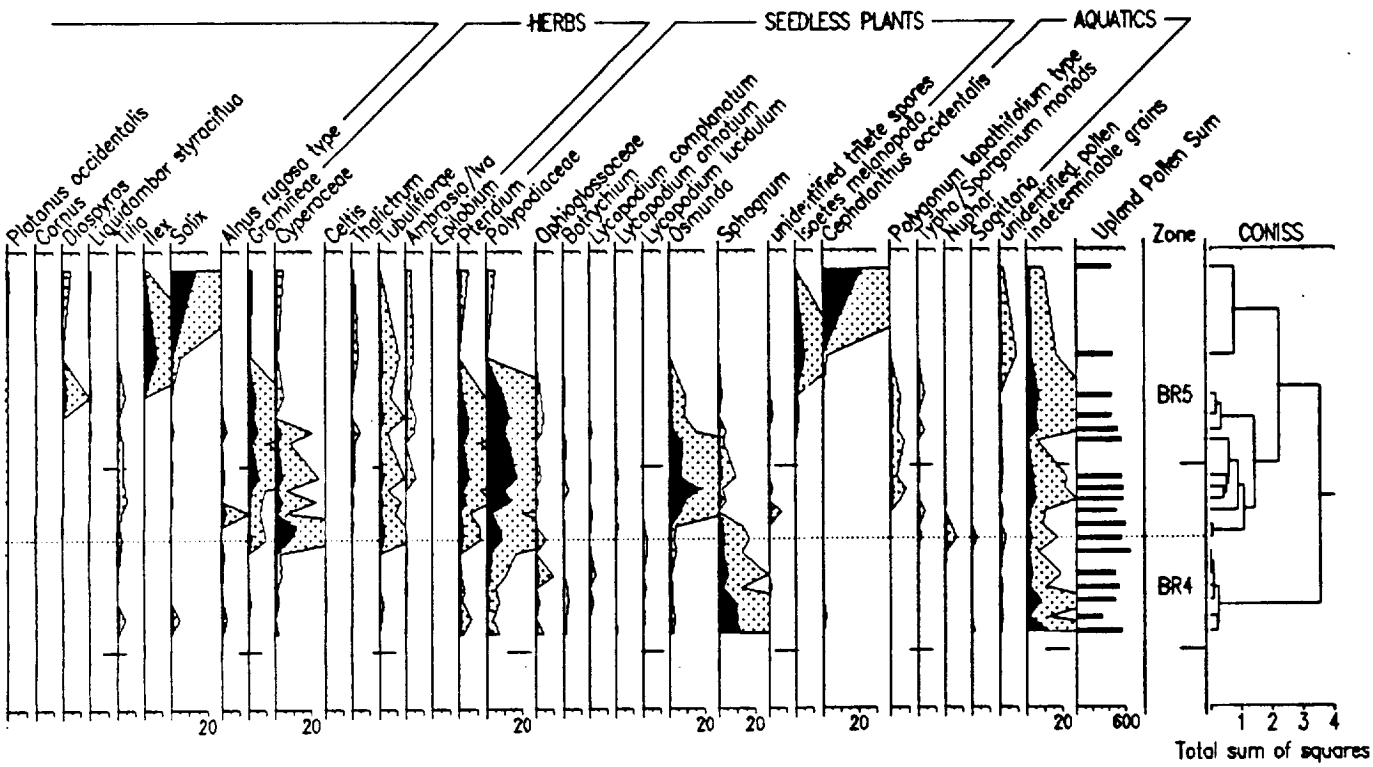

HERBS
MOSSES, SEEDLESS PLANTS
AQUATICS, MARSH PLANTS
Gramineae
Cyperaceae
Sanguisorba canadensis
Cerlis
Umbelliferae
Thalictrum
Tubuliflorae
Ambrosia/Iva
Artemisia
Epilobium
Arceuthobium
Pteridium
Polypodiaceae-Dryopteris type
Botrychium
Lycopodium complanatum
Lycopodium annotinum
Lycopodium obscurum
Osmunda
Sphagnum
Selaginella selaginoides
unidentified Trilete spores
Isoetes melanopoda
Cephalanthus occidentalis
Potamogeton capathifolium type
Typha
Sparganium monotis
Nuphar
Menyanthes trifoliata
Sagittaria
unidentified pollen
indeterminable grains
Upland Pollen Sum
Zone
CONISS
BR6
BR5
BR4
BR3c
BR3b
BR3a
BR2
BR1
20
20
20
20
20
20 40
800
5 10 15 20
Total sum of squares

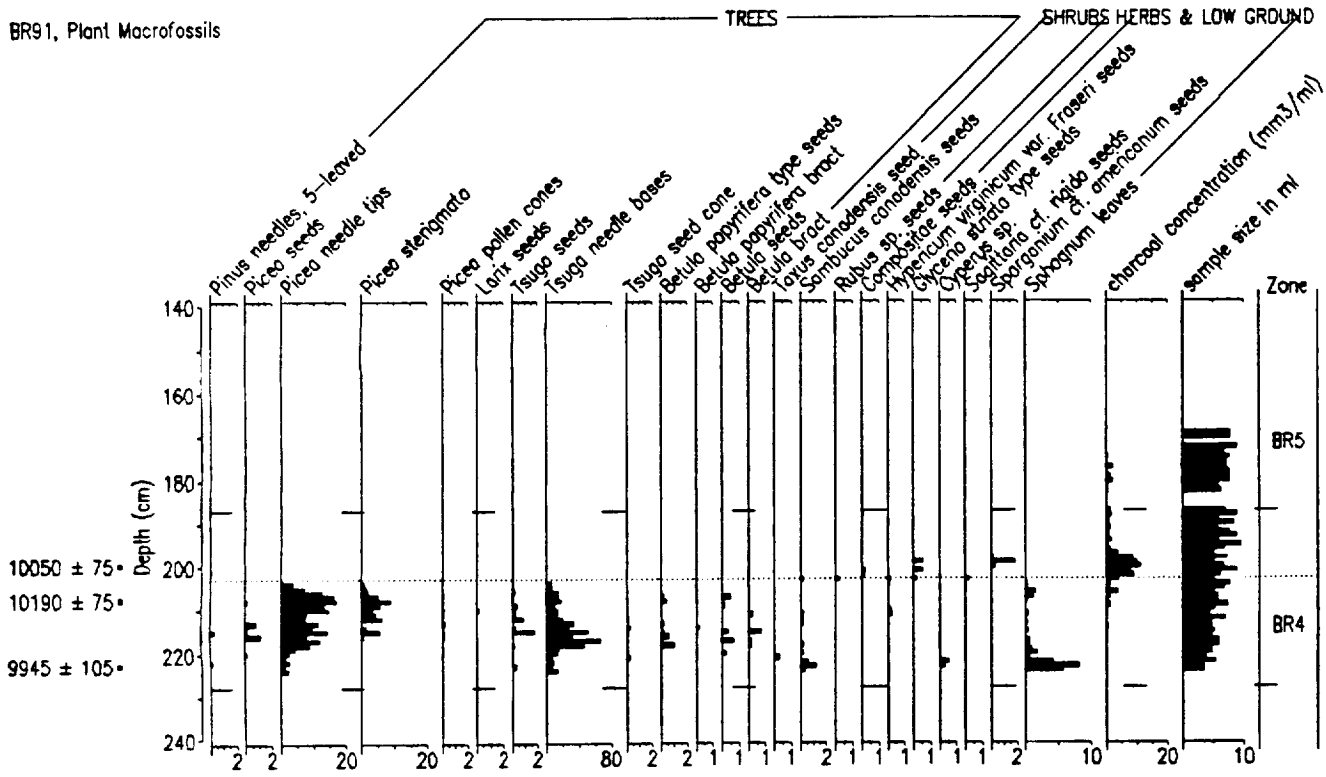

BR92, Plant Macrofossils
TREES
UPLAND SHRUBS & HERBS
Pinus needles, 2-leaved
Pinus needles, 3-leaved
Pinus strobus needles, 5-leaved
Picea seeds
Picea needle tips
Picea stenigmata
Abies needle tips
Larix seeds
Larix needle fragments
Tsuga seeds
Tsuga needle bases
cf. Chamaecyparis thyoides stem
Betula populifolia type seeds
Alnus seeds
Alnus cone bracts
Acer spicatum seeds
Cornus canadensis seeds
Crataegus sp. seeds
Salix buds
Sambucus canadensis seeds
Rubus sp. seeds
Fragaria seeds
Compositae seeds
Bidens sp. seeds
Oxalis seeds
Scrophularia seeds
Verbena cf. hastata seeds
Hypericum virginicum var. Fraseri seeds
Potentilla sp. seeds
Viola cf. lanceolata seeds
Depth (cm)
50
100
150
200
250
300
350
400
450
500
7500 ± 60
8890 ± 60
11280 ± 60
12200 ± 70
12230 ± 70
12730 ± 60
14180 ± 60
1 1 1 1 4 20 2 1 1 1 4 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 4 1 1

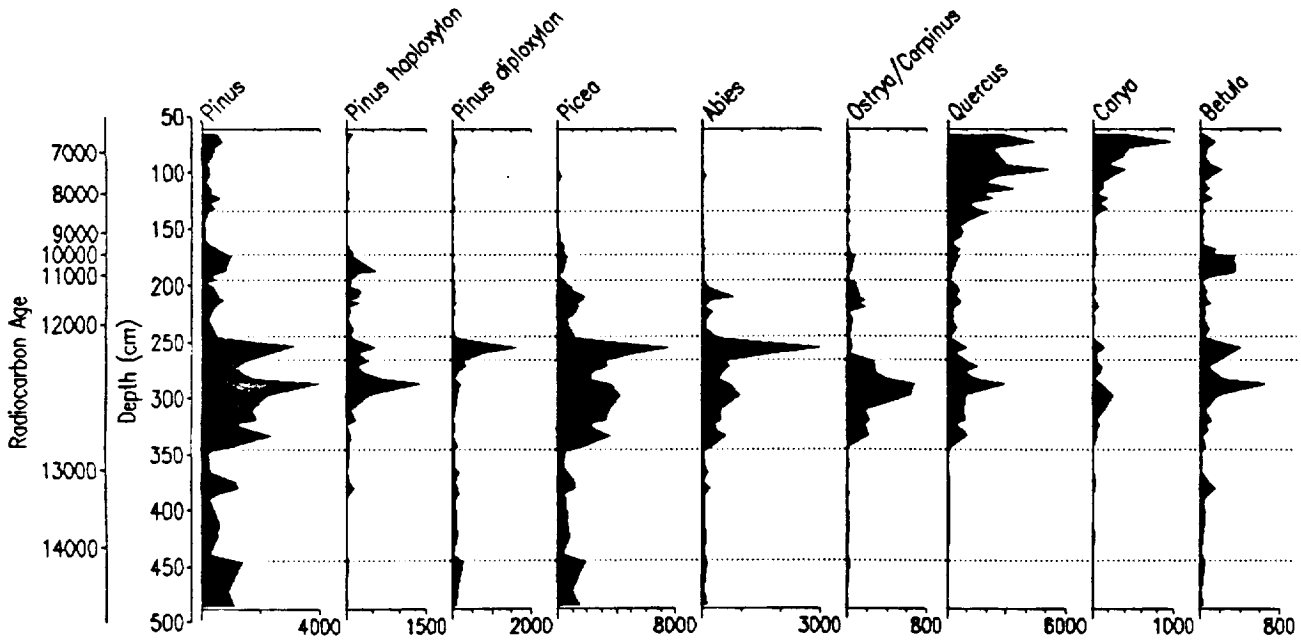

LOWLANDS: SWAMPS, SHORES & WET WOODS
AQUATICS
Menyanthes trifoliata seeds
Cephalanthus occidentalis seeds
Glyceria striata type seeds
Cyperus cf. filiculmis seeds
Cyperus lenticular-type seeds
Cyperus sp.
Carex stipata seeds
C. crinita seeds
C. cf. lurida seeds
C. lupulina seeds
Carex sp. seeds
Scirpus polyphyllus type seeds
S. atrovirens type seeds
Scirpus sp. seeds
Eleocharis sp. seeds
Sagittaria cf. rigida seeds
Dulichium arundinaceum seeds
Sparganium cf. americanum seeds
Polygonum cf. punctatum seeds
Polygonum sp. seeds
Sphagnum leaves
Isoetes melanopoda megaspores
Potamogeton spirillus type seeds
P. foliosus type seeds
Potamogeton sp. seeds
Vallisneria seeds
Characeae oogonia
Nymphaeaceae seeds
Nuphar seeds
Najas flexilis seeds
charcoal concentration (mm3/ml)
sample size in mL
Zone
BR6
BR5
BR4
BR3c
BR3b
BR3a
BR2
BR1
1 1 1 1 1 2 1 1 2 1 1 3 3 1 1 1 1 1 1 1 1 20 1 1 1 1 2 1 1 1 4 20

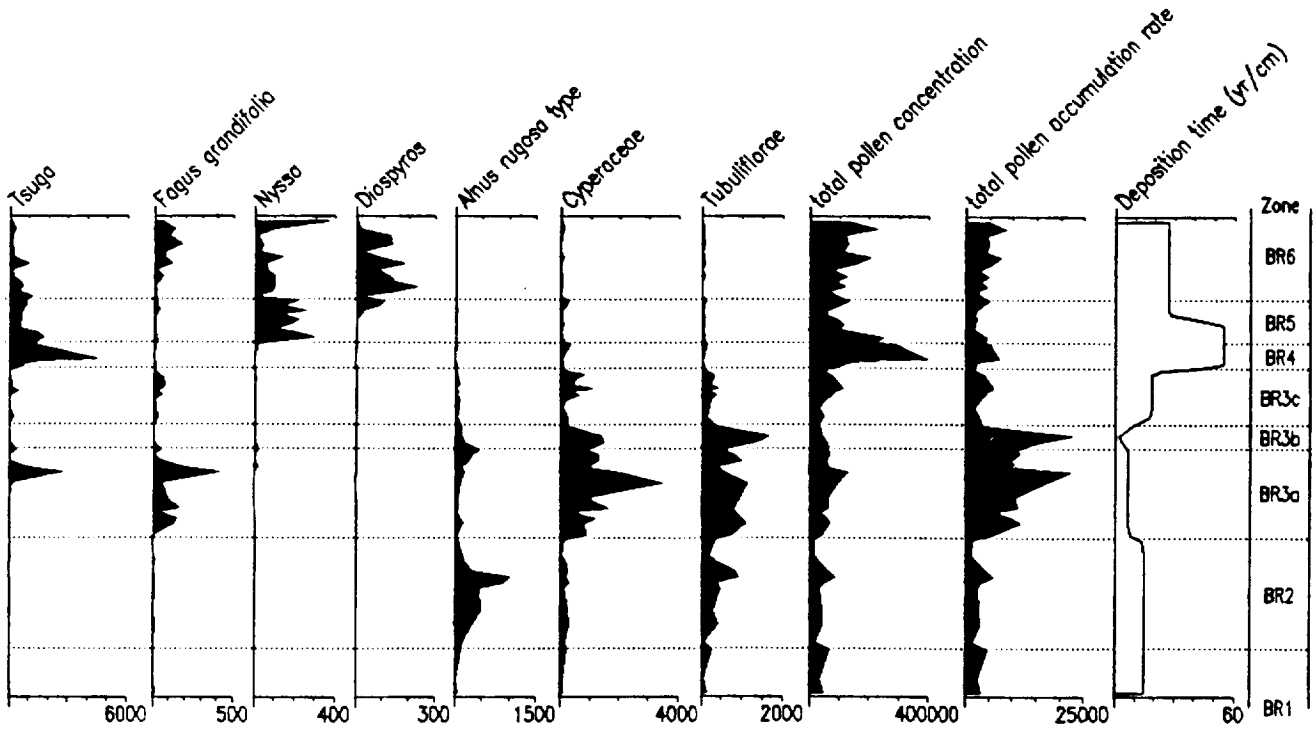
BR91, Pollen Percentages




HERBS
SEEDLESS PLANTS
AQUATICS
Platanus occidentalis
Cornus
Diospyros
Liquidambar styraciflua
Tilia
Ilex
Salix
Alnus rugosa type
Gramineae
Cyperaceae
Celtis
Thalictrum
Tubuliflorae
Ambrosia/Iva
Epilobium
Pteridium
Polypodiaceae
Ophioglossaceae
Botrychium
Lycopodium complanatum
Lycopodium annotinum
Lycopodium lucidulum
Osmunda
Sphagnum
unidentified triete spores
Isoetes melanopoda
Cephalanthus occidentalis
Polygonum lapathifolium type
Typha/Sparganium
Nuphar
Sagittaria
unidentified pollen
indeterminable grains
Upland Pollen Sum
Zone
CONISS
BR5
BR4
20
20
20
20
20
20
20
600
1 2 3 4
Total sum of squares


BR91, Plant Macrofossils
TREES
SHRUBS HERBS & LOW GROUND
Pinus needles, 5-leaved
Picea seeds
Picea needle tips
Picea stenigmata
Picea pollen cones
Larix seeds
Tsuga seeds
Tsuga needle bases
Tsuga seed cone
Betula papyrifera type seeds
Betula papyrifera bract
Betula seeds
Betula bract
Taxus canadensis seed
Sambucus canadensis seeds
Rubus sp. seeds
Compositae seeds
Hypericum virginicum var. Fraseri seeds
Glyceria striata type seeds
Cyperus sp. cf. rigido seeds
Scutellaria sp. cf. americanum seeds
Sparganium sp.
Sphagnum leaves
charcoal concentration (mm3/ml)
sample size in ml
Zone
Depth (cm)
140
160
180
200
220
240
10050 ± 75•
10190 ± 75•
9945 ± 105•
BR5
BR4
2 2 20 20 2 2 2 80 2 2 1 1 1 1 2 1 1 1 1 1 1 2 10 20 10


Pinus
Pinus haploxylon
Pinus diploxylon
Picea
Abies
Ostrya/Carpinus
Quercus
Corya
Betula
Radiocarbon Age
Depth (cm)
7000
8000
9000
10000
11000
12000
13000
14000
50
100
150
200
250
300
350
400
450
500
4000
1500
2000
8000
3000
800
6000
1000
800


Tsuga
Fagus grandifolia
Nyssa
Diospyros
Alnus rugosa type
Cyperaceae
Tubuliflorae
total pollen concentration
total pollen accumulation rate
Deposition time (yr/cm)
Zone
BR6
BR5
BR4
BR3c
BR3b
BR3a
BR2
BR1
6000
500
400
300
1500
4000
2000
400000
25000
60